

TABLE 1: CONSTITUENTS FOR SAMPLING AND PURPOSE

Constituent	Description	Method/lab code	Analysis purpose	Site purpose
Field values	Water temperature, pH, conductance, turbidity, ORP, DO	Orion 130A, Orion 250A+, Oakton T-100 (field meters)	Standard purge monitoring parameters for sample stability criteria. Hydrogen ion activity and D.O. state.	Standard data and allow for comparison to previous field parameter values.
Dissolved ferrous iron	Fe ²⁺	Hach Field kit Model IR 18C	Redox identification, iron available for oxide reactions. U+6 can be locked up in some cases with oxide formation.	Not collected at site but easily obtainable data.
Dissolved oxygen	DO	For groundwater DO analyses, visual colorimetric analyses	Additional measurement of D.O. as a check on probes.	Check measurement on D.O. probe given the importance of redox state on U mobility.
Alkalinity	Alkalinity as CaCO ₃	¹ MCAWW 2320B	Anion and cation balance. Understand carbonate and bicarbonate reactions. U+6 mobile under high carbonate concentrations in some cases. Alkaline leaching process was employed at tailing sites.	Important constituent for charge balance and to understand carbonate concentrations.
Total organic carbon	TOC	USEPA 415.3	General carbon availability gauge. Microbial-mediated reduction of uranium can be stimulated by the availability of an electron donor.	Limited data available at the site but provides useful information on electron donor availability.
Major anions	Br, Cl, F, SO ₄	¹ MCAWW 300.0A	Major anions for geochemical reactions and water type.	Identify water type.
Major cations	Ca, Mg, Na, K	¹ SW846 6010B	Major cations for geochemical reactions and water type.	Identify water type.
Trace elements	224 trace elements	¹ SW846 6010B, 6020	Includes important elements such as selenium and molybdenum; CO-CONTAMINANTS.	Required constituents for monitoring COCs.
Nitrogen	NO ₃ + NO ₂ as N, NO ₂ as N	353.2	High nitrate concentrations have been associated with the site. Nitrate reactions can affect uranium concentrations. Presence of nitrate oxidized sulfur ores and previously immobile U+4 (PARADIS ET AL., 2016).	Understanding sources of nitrate is important for assessing U mobility.
Gross alpha/beta		³ USEPA 900.0	Standard screening method for radioactivity; parameter measured at site.	Required constituents for monitoring COCs.
Radium isotopes	Alpha-emitting isotopes of Ra (226Ra and 228Ra)	¹ USEPA 903.0 and 904.0	Radium 226 is in the U-238 decay series. Radium 226 has a half life of 1600 years and decays into radon gas. Radium 228 is in the thorium-232 decay series. Radium has a half life of 5.75 years. Radium 226 is a good indicator of waste water contamination from mines and mills (Kaufman et al., 1976).	Identify natural and anthropogenic contaminant of U decay series.

Constituent	Description	Method/lab code	Analysis purpose	Site purpose
Radon-222	Radon-222	SM 7500-Rn/CIN50318	Radon 222 is a decay product of Radium 226. High radon-222 has been associated with fault locations and uranium sources.	Identify natural and anthropogenic contaminant of U decay series.
Uranium isotopes	U-234, U-235, U-238	¹ USEPA 907.0 and 910.0	There are three main isotopes of uranium (U-234, U-235, and U-238). U-238 is a weakly radioactive metal, and contributes to low-level background radiation in the environment. U-238 has a very long half-life of 4.47 billion years. Enriched U-235 is used as fuel in nuclear reactors and in nuclear weapons. Depleted uranium, which is poor in U-235 but rich in U-238, is used for commercial purposes. Uranium is common in specific types of igneous, metamorphic, and sedimentary rocks. Recent research indicates that increased concentrations of uranium in groundwater are caused by mobilization of uranium present in soil with irrigation waters containing bicarbonates. Also, nitrate can mobilize uranium through a series of bacterial and chemical reactions. Groundwater in the basin unaffected by mining has been found to have 234U/238U values ranging from 1.5 to 2.7. Ratios exceeding unity (secular equilibrium) result from alpha recoil of solid-phase 238U over geologic time causing the 234U daughter to be placed in favorable leaching sites. As ore bodies were dewatered, increased availability of oxygen caused uranium to dissolve rapidly without preference to 234U over 238U.	Identify natural and anthropogenic contaminant.
Stable isotopes of water	2H/1H, 18O/16O	Révész and Coplen, 2008a and b	Assessment of recharge conditions, fractionation processes such as evapotranspiration, and sources of water.	Water affected by evaporation of tailings water from LTP can be identified.
Sulfur isotopes of sulfate	δ34S, δ32S		Sulfur reactions that are involved with U mobilization. Availability of pyrite and sulfur oxidation can impact U mobilization. These processes are visible with 32S and 34S ratios.	There is some evidence of gypsum availability in geochemical reactions. Liberation of oxygen from dissolution of gypsum could enhance U mobilization.
Nitrogen isotopes	δ15N of NO3, δ14N of NO3, δ18O of NO3, δ16O of NO3		Theoretically, identify nitrate controls on U mobilization. Denitrification processes can mobilize U and nitrogen isotopes can identify denitrification processes.	There are several sources of nitrate at the site including tailing operations and local septic systems.
Carbon isotopes	δ13C of DIC, δ13C of DOC, δ12C of DIC, δ12C of DOC		Useful for identifying carbonate reactions and carbon dioxide influences on chemistry. Carbonate is an important factor in U mobilization.	The alluvial system has carbonate waters that may promote U mobilization. Carbon isotopes may be useful for identifying mixing in Chinle.

Constituent	Description	Method/lab code	Analysis purpose	Site purpose
Carbon isotopes	Carbon-14	RA-420 LIQUID SCINTILLATION	Carbon 14 has a large half life and is used to date very old waters. Groundwater in study area may contain a mix of old and new waters and this would help identify bimodal ages.	Chinle waters may contain a mixture of old water.
Dissolved gases	N2, Ar, CO2, CH4, O2	⁴ See below	Useful for looking at recharge conditions at time of water entering the subsurface.	Local and regional recharge may be distinguishable with measurements of dissolved gases. Measurements also provide additional check on oxygen and redox state.
GW dating: Tritium/Helium-3	Helium, Neon, 3He/4He with tritium by 3He ingrowth	USGS Schedule 1033 and Lab Code 2112	A primary age dating method for recent (60 years) water. Peak TU is in late 1950's-early 1960's. Age is calculated from parent/daughter decay of ³ H and ³ He.	Selective wells be analyzed to assess recharge rates and time of travel. Understand formation of mixing zones in the Chinle and help tag U concentration to general ages of recharge.
CFCs	CFS		A primary age dating method for recent (40 years) water. Peak is in late 1980s.	Will be used as a check on tritium/helium ages at a subset of wells.
Helium-4	Helium, Neon, 3He/4He with tritium by 3He ingrowth	Gas chromatography	Screening tool to assess terrigenous Helium influence on tritium-helium dating.	Selectively analyzed constituent in Chinle waters to assess terrigenous Helium. Faults may provide an avenue of terrigenous Helium.

¹ U.S. Environmental Protection Agency, 2009.

² Al, Sb, As, Ba, B, Be, Cd, Cr, Co, Cu, Fe, Li, Pb, Mn, Hg, Mo, Ni, Se, Si,

³ U.S. Environmental Protection Agency, 1993.

⁴{N2, Ar} R. F. Weiss, 1970, Deep-Sea Res., vol. 17, 721-735. R.F.

{O2} B. B. Beson and D. Krause, 1980, Limnol. Oceanogr. 25(4) 662-671; 1984, Limnol. Oceanogr. 29(3), 620-632.

{CH4} D.A. Wiersburg and N.L. Guinasso, 1979, J. Chem. Eng. Data Vol. 24, 356-360.



DRAFT PROPOSAL SUBMITTED TO: EPA Region 6

**FIELD INVESTIGATIONS TO HELP SUPPORT THE ASSESSMENT
OF BACKGROUND CONCENTRATIONS FOR URANIUM (U) AT
THE HOMESTAKE MINING COMPANY, SUPERFUND SITE**



Aerial view of Uranium tailing pile (LTP) at the Homestake Site

U.S. Department of the Interior
U.S. Geological Survey

Background

The Homestake Mill Site is located in Cibola County, just north of the village of Milan and town of Grants, New Mexico. The Site processed raw ore material from external sites starting in 1958; from 1958 to 1990 milling activities continued. A large waste tailing pile (LTP) was constructed starting in the early 1960's. The LTP contained no liner and processed materials including waste water as a transporting device were deposited onto the land surface into the tailings. Infiltration of waste water occurred into a surficial alluvium aquifer from both the LTP and a small tailings pile (STP). In 1977 until the present, various levels of remedial activities have been initiated to contain the spread of a uranium (U) plume emanating from the site and associated processing activities. These activities have included flushing of the tailings from 2000 to 2015. Other contaminants of concern (COC) include thorium-230, radium-226, radium-228, selenium (Se), molybdenum, sulfate, and total dissolved solids. Private wells in the subdivisions south of the Site have shown elevated levels of COCs. All residents have been hooked up to safe water source from the Village of Milan. The Site is underlain by alluvium with a saturated thickness that varies from west (thicker; 50 ft) to east (thinner; 20 ft). The bulk transmissivity of the alluvium also varies from west (10,000 gal/day/ft) to east (1,000 gal/day/ft). Underlying the alluvium are rock formations of the Chinle and lowermost San Andres formations. The Chinle formation consists of three aquifers (upper, middle, and lower) separated by shale. The San Andres formation is considered one aquifer. Some or all (the three Chinle aquifers in particular) of the four underlying rock aquifers subcrop in various locations in the basin. The dip of the Chinle and San Andres aquifers is approximately to the north, which is counter to flow in the alluvium. Alluvium groundwater recharges the Chinle aquifers at subcrop locations. The rate of recharge from the alluvium to the Chinle is likely time varying with time-varying changes in saturated thickness of the alluvium as waters from upgradient mining legacy locations in the San Mateo basin were transported downgradient. The lower rock aquifers are also intersected by a west and east fault that bounds the overlying area of the LTP. The underlying rock aquifers are uplifted to the west.

Clean-up standards for the Site are based on concentrations of COCs in the groundwater upgradient of the site in the alluvium. Due to recharge of groundwater from the alluvium to the Chinle aquifers, a similar standard is being applied to the Chinle. The clean-up standards do not meet federal standards partly based on the pervasive mining activities in the upper basins and the potential for regional contamination to impact local contamination. The site standard for U is 0.16 mg/L for the alluvial aquifer. Examination of U concentrations from Fig. 6.1 (Hydro-Engineering LLC, 2001) north of the LTP shows low concentrations of U (< 0.16 mg/L) immediately north central of the LTP, and higher concentrations of U (> 0.16 mg/L) further north.

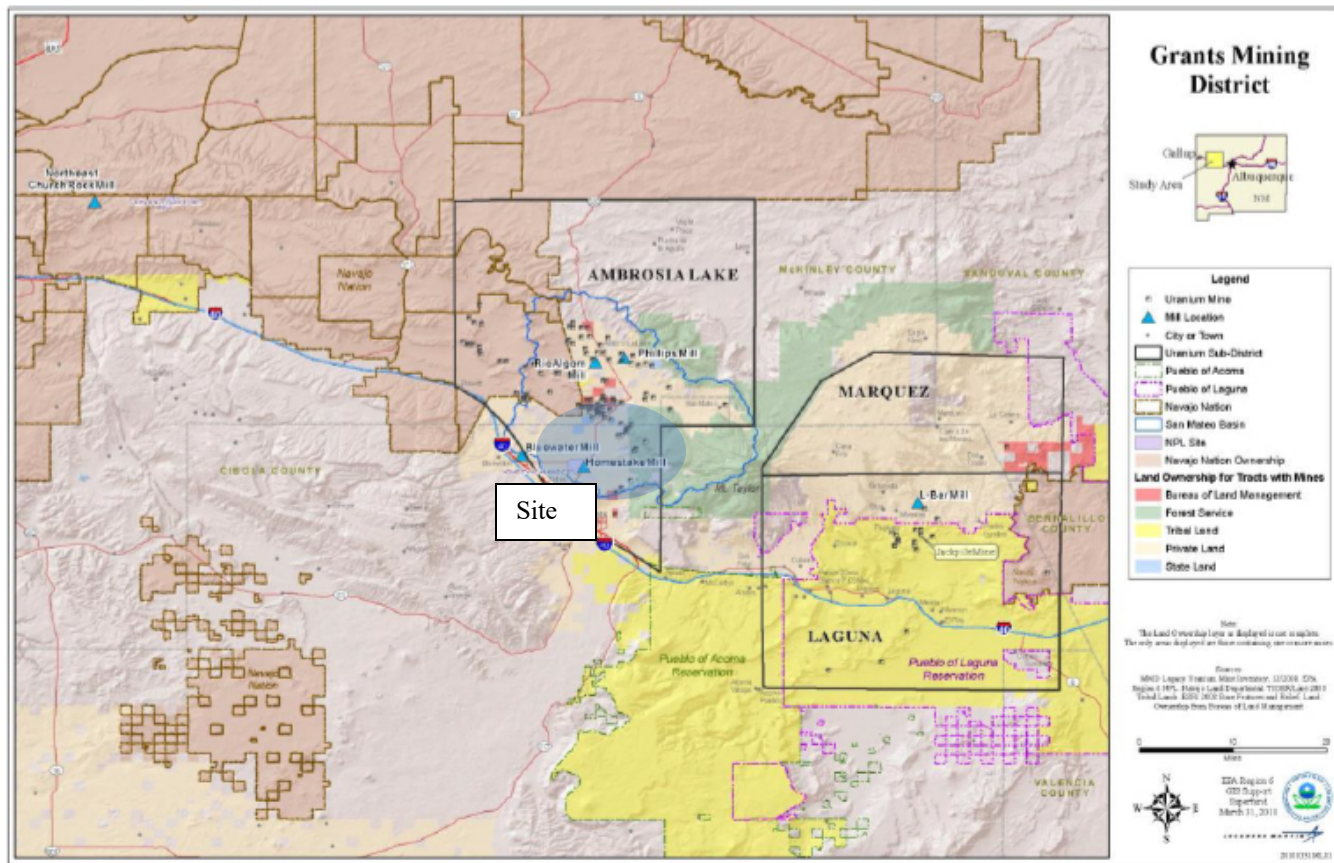


Figure 1. Map showing study site and Grants Mineral Belt area (from U.S. EPA).

Problem

Clean-up standards for the Site are based on concentrations of COC in the groundwater located proximal to the site. Site background levels for COCs were established for alluvial and three separate Chinle aquifers for uranium (U), selenium (Se), molybdenum (Mo), chloride (Cl), nitrate (NO₃), sulfate, and total dissolved solids (TDS) using site specific data. The concentration for U is 0.16 mg/L in the alluvium aquifer, which is approximately five times the EPA 0.03 mg/L Maximum Contaminant Level (MCL). Historical regional data for the Grants Mineral Belt area show average background concentrations of 0.023 mg/L (Kaufman et al., 1976).

Cleanup levels for the Site were derived from nine wells specified as upgradient to the LTP. Wells far upgradient of the site are affected by regional mining/milling contamination as shown by increases in contaminants associated with milling wastes (Homestake Mining Co., 2015). The lower San Mateo basin, in which the site is located, is situated downgradient from milling activities in the upper San Mateo basin. Closer to the Site, wells located above the Site (north is generally upgradient of the regional flow system) could be affected by local mounding and radially outflow of groundwater from recharge of tailing waste water. Several of the proximal (called near upgradient wells) wells show a wide range of U concentrations from 0.02 to 0.23 mg/L based on 1995-2004 data as reported in the Homestake Mining Co., 2015 report. Recall regional U concentrations as reported by Kaufman et al. (1976) indicate an average of 0.023 mg/L. Thus for values above 0.1 mg/L (order of magnitude greater) appear high compared to historical data.

The analysis of Site historical chemistry data (COCs), which span from 1975 to present, provides one line of evidence on the impact of regional milling activities on water quality. In particular, increases in U and Se concentrations can be seen in far upgradient wells during the monitoring period that can be interpreted to result from transport or arrival times of upgradient, regional waters affected by mines. However, it is more difficult to identify local waste water impact using this technique because monitoring began 15 to 20 years after operation started at Homestake so transport and arrival of COCs from local sources could have occurred prior to 1975. As a result, additional lines of evidence are needed to differentiate water sources besides arrival times of COCs. A number of studies have used chemical fingerprinting as a means to associate water type from multiple U sources (Basu et al., 2015; Christensen et al., 2004; Zielinski et al., 1997; Yabusaki et al., 2007).

U mobilization is controlled in part by redox, carbonate, Ca concentrations, and iron oxide reactions (fig. 2). The dominant ionic species is typically U^{+6} . Knowledge of these reactions is important when identifying transport pathways of U and assessing the distribution of U as a COC. Wu et al. (2010) studied the effect of nitrate in geochemical process affecting U (fig.2).

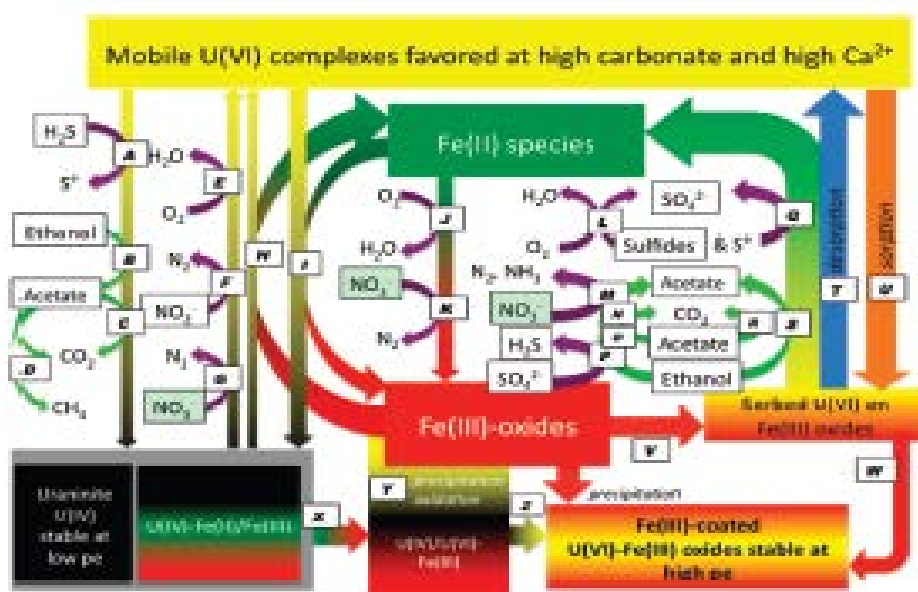


Figure 2. Geochemical processes affecting U mobilization from Wu et al.(2010).

Objective

The goal of this project is to help differentiate chemical signatures from the three main sources of water in the alluvium and Chinle aquifers near the Homestake Site, Milan, NM. The three main sources include: (1) waters unaffected by local or regional tailing operations, (2) waters affected by local tailing operations, and (3) waters affected by regional, upgradient tailing operations in the basin. An important objective of this work includes identifying anthropogenic and background water chemistry of U at selected specific well locations in the vicinity of the Homestake Mill site for the alluvium and Chinle aquifers.

Scope

This planned, field-based study is focused on understanding natural and anthropogenic sources of U in the central to lower San Mateo basin by the Homestake Site. Field testing will include borehole geophysical logging of optical televiewer, natural gamma and spectral gamma, caliper, fluid temperature and resistivity, resistivity, electromagnetic induction (at non-metallic wells), and ambient and pumped flowmeter. Fluid logs will be run twice, before flowmeter testing and after pumped flowmeter testing. A maximum of eight wells will be logged. At up to five wells, a profile of passive samplers will be deployed to help assess vertical chemistry in wells. Purge samples will be collected following SOP of the Site. Prior to, during, and after purging for sampling, well profiles of water temperature and conductivity will be collected. A maximum of 25 wells will be sampled for major cations and anions, trace metals, radiochemical screening, radioactive isotopes of U and radium, and radon, stable isotopes, a variety of carbon isotopes, sulfur isotopes, and nitrogen isotopes. Age dating of CFCs and tritium-helium will also be collected. The distribution of wells where sampling is planned (subject to field inspection) is shown in figure 3.

For the alluvium wells, sampling of wells distal and proximal to the Homestake Site is planned to help identify chemical signatures from regional and local sources of water. For the Chinle aquifers, a primary focus is understanding differences between previously defined mixing and non-mixing zones of water that are impacted by recharge from the alluvium.

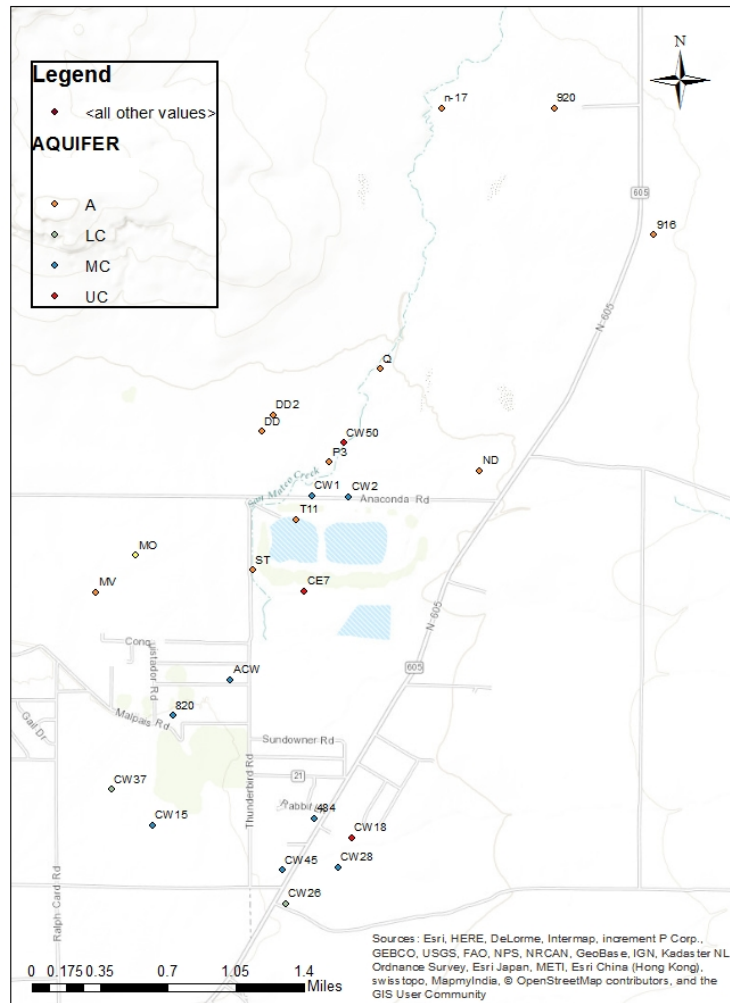


Figure 3. Location of wells planned for sampling [A= alluvium; UC= upper Chinle; MC= middle; LC= Lower].

Approach

The USGS proposes seven major work tasks. However, there are three major field activities that include (1) borehole geophysical logging, (2) passive sampling profiling, and (3) water-quality sampling. Individual tasks are discussed below.

Task 1: Development of a workplan, QAPP, and health and safety report (includes reconnaissance)

Task 2: Borehole geophysical logging

Task 3: Installation of passive sampling profile

Task 4: Water-quality sampling

Task 5: Data compilation and reporting

Task 6: Data analysis and presentation

Task 7: Interpretive reporting

Task 1: A workplan will be developed to provide detailed steps in data collection and analysis of the project. A project QAPP is needed to ensure quality control and assurance. A health and safety plan will be produced to ensure conformity with other activities at the Site. We propose a well reconnaissance trip to help develop a well specific workplan. The well reconnaissance trip will include verifying field locations of wells using a handheld GPS unit and inspecting the wells for field sampling. A USGS station identification header will be established from the GPS coordinates.

Task 2: This task includes classic borehole geophysical, and hydrogeophysical investigations. Up to eight wells will have borehole geophysical logs run for optical televiewer, caliper, natural gamma and spectral gamma, fluid resistivity, fluid temperature, and electromagnetic (in non-metal wells if any). Natural gamma and spectral gamma can be used to identify uranium and thorium decay series in formations http://water.usgs.gov/ogw/bgas/spectral_gamma/. Flowmeter logs using an EM or Heat-Pulse Flowmeter will be run in selected wells under ambient and pumped well conditions to help map flow contributions with depth in the well. We suggest running fluid logs twice--pre and post purging (after pumped flowmeter testing) to identify water capture interval of wells.

Task 3: Installation of passive samplers to profile well concentration will be done in up to five wells. A profile of samplers allows for discrete sampling of wells to help identify variability of COCs. The nylon mesh passive sampler has been shown to be an effective sampler for Se (Vroblesky et al, 2003). The number and configuration of passive sampler deployment relative to screen interval and depth below water level are important factors in understanding profile concentrations in addition to sampler condition. The number of samplers deployed will be well specific but typically range between three and ten per well. We anticipate a maximum of 40 samples including duplicates will be collected for U and Se. The project QAPP will identify additional laboratory testing that will be undertaken to ensure high quality samples are collected.

Task 4: Groundwater-quality sampling will follow similar procedures as outlined in the project SOP (Hydro-Engineering, LLC, 2001). Prior to purging, the depth of the well will be sounded and the water level measured from an established measurement point. Prior to, during, and after purging for sampling, well profiles of water temperature and conductivity will be collected (if possible) to help identify capture intervals of wells during purging. For monitoring wells, two casing volumes will be purged and field parameters monitored for field stabilization. A combination of monitoring wells, existing remedial extraction wells, and residential wells will be sampled. For existing remedial extraction wells and residential wells in use, samples will be collected from the existing infrastructure and rely on existing withdrawals. For residential wells offline but with existing pump equipment, the well will be flushed for two volumes similar to monitoring wells. Samples are filtered with a .45 micron filter for selected constituents. During purging, field parameters will be collected including water temperature and conductivity, pH, dissolved oxygen, oxidation-reduction potential, and turbidity. Field kits for oxygen and ferrous iron will be used to measure concentrations in each constituent once during purging according to methods described by Harte et al. (2012).

Constituents for chemical analyses have been selected to facilitate identification of chemical fingerprinting for project objectives (see table 1, separate attachment). Constituents were also selected to facilitate local and regional comparison of water quality (Langman et al., 2012). Not all constituents will be collected at each well (see table 2, separate attachment). Table 2 identifies up to 25 wells will be sampled. However we anticipate that some wells may not be accessible for sampling as determined during the well reconnaissance trip. For planning purposes, we are planning for 25 samples plus duplicates.

Task 5: A U.S. Geological Survey data report series (Open-File or data-report) is anticipated to facilitate the distribution of information from this project. This will allow for the quickest delivery of high quality information from this effort. The report is non-interpretive, so follow-up, and interpretive, deliverables are scheduled.

Task 6: Interpretation of chemical results is needed to address project objectives. A presentation is planned to highlight important findings and to allow for collaborative discussions with stakeholders.

Task 7: Task 6 can be viewed as a preliminary analysis of findings. However, a peer-reviewed short journal paper is planned to provide final interpretive findings. The paper will focus on identifying chemical signatures that helped differentiate processes, water types, and sources of water to the groundwater of the study area. We believe production of a journal paper is the most cost-effective approach to producing a citable, USGS approved interpretive product. A companion factsheet will be produced to summarize important findings from the technical paper. The factsheet target audience is non-technical so as to convey and explain conclusions from the study to stakeholders.

Quality Assurance Plan

Quality assurance measures will be followed to ensure the quality, precision, accuracy, and completeness of the data generated and collected during the study. The quality assurance objectives for the measurement and collection of data are to ensure the data will:

- Withstand scientific scrutiny
- Be obtained by methods appropriate for its intended use, and

- Be of known precision, accuracy, completeness, representative, and comparability.

All data will be reviewed by USGS Texas Water Science Center personnel to ensure the data is properly documented. Additionally, the project will be reviewed by USGS management personnel on a quarterly basis to ensure project timelines and objectives are met. Erroneous well data with incorrect location information, missing or incorrect header information, unknown well completion, poor tool calibrations, and unsuitable borehole environments can introduce errors during the interpretation of hydrostratigraphic information and will not be used for the interpretation of the hydrostratigraphy. All borehole geophysical log data will be collected according to the following American Society of Testing and Materials (ASTM) borehole geophysical standard procedures: 1) ASTM Standard Guide for Planning and Conducting Borehole Geophysical Logging - D5753–05 (ASTM, 2010), 2) ASTM Standard Guide for Conducting Borehole Geophysical Logging: Mechanical Caliper - D6167–97 (ASTM, 2004), and 3) ASTM Standard Guide for Conducting Borehole Geophysical Logging Electromagnetic Induction - D6726–01 (ASTM, 2007). All logs will be collected in digital format and will be recorded in the proprietary format of the data acquisition equipment used to collect the logs. These proprietary data formats will be converted to and stored as Log ASCII Standard (LAS) (Canadian Well Logging Society, 2011) tabular data and presented as chart logs in a portable documents format (PDF).

For passive samplers, an equipment blank sample is collected and submitted for analysis after deployment of all samplers downhole (pre-monitoring). The equipment blank serves multiple purposes, as a blank of the deionized water and to ensure no contamination of U or Se occurred pre-deployment of samplers. If U and Se concentrations are detected above detection level, a lab blank of the deionized water will also be submitted. Sample duplicates are collected at each well by doubling up on samplers at fixed locations downhole. Sample duplicates are collected from separate bottles but similar depths. A test of the nylon-screen sampler to equilibrate to known U and Se concentrations will be done using a lab grade spike prior to deployment. The condition of the samplers upon collection is noted upon retrieval for any signs of staining or leakage.

The sampling SOP established by Homestake indicates that collection of water samples occur after a minimum of two well casing volumes are evacuated. Our samples will be collected using the same criteria (following previously purged volume amounts). An inline flowmeter will be used to track purge volume and allow better tracking of response of field parameters to purging. A portable YSI will be calibrated to known standards. New sampling tubes will be used at each well in order to avoid a risk of cross-contamination between wells. In addition, downhole submersible pumps will be decontaminated after each well.

Data Management Plan

Well location and construction information will be stored in the USGS NWIS database. Geophysical logs will be archived in appropriate Texas WSC repositories. Quality data will be stored in USGS NWIS database.

Relevance and Benefits

This study provides important information on helping to differentiate regional and local impact on COCs, particularly U, in the vicinity of the Homestake Site. Natural sources of U will be better understood as it relates to specific well concentrations. In this regard, a reassessment of U background concentrations, if needed, can be undertaken. The integrated, field-based approach, between geophysical logging, contaminant profiling, and chemical signature identification is a comprehensive approach to obtaining additional lines of evidence in the identification of U background concentrations.

Deliverables

A data report is planned as an initial product to facilitate data transfer to stakeholders. A draft report will be available in October 2016. A presentation to stakeholders is planned to allow for an initial summary of interpretive findings. All data also will be publicly available online through the USGS report series. A peer-reviewed journal will be published at the conclusion of this study. A companion factsheet will be produced to summarize important findings from the technical paper.

Timeline

There are many factors that can affect the timeline. The timeline below (table 3) represents an estimate of the time required to fulfill the proposal.

Table 3. Timeline for project.

4/17/16

Task	May	June	July	Aug	Sept	Q1-FY17	Q2FY17	Q3-FY17
Task 1: Development of a workplan, QAPP, and health and safety report								
Task 2: Borehole geophysical logging								
Task 3: Installation of passive sampling profile								
Task 4: Water-quality sampling								
Task 5: Data compilation and reporting								
Task 6: Data analysis and presentation								
Task 7: Interpretive reporting								

References

- American Society of Testing and Materials, 2004, Standard guide for conducting borehole logging—Mechanical caliper: American Society of Testing and Materials (ASTM) D 6767–97, 6 p.
- Basu, Anirban, Shaun T. Brown, John N. Christensen, Donald J. DePaolo, Paul W. Reimus, Jeffrey M. Heikoop, Giday Woldegabriel, Ardyth M. Simmons, Brian M. House, Matt Hartmann, and Kate Maher, 2015, Isotopic and Geochemical Tracers for U(VI) Reduction and U Mobility at an in Situ Recovery U Mine; *Environmental Science & Technology*, v.49, no. 10, pp. 5939-5947, at DOI: 10.1021/acs.est.5b00701
- Canadian Well Logging Society, 2013, LAS information—Log ASCII Standard (LAS) software: accessed May 13, 2013, at http://www.cwls.org/las_info.php
- Christensen, J.N., Dressel, P.E., Conrad, M.E., Maher, Kate, and Depaolo, D.J., 2004, Identifying the sources of subsurface contamination at the Hanford Site in Washington using high precision Uranium isotopic measurements: *E&S&T* v. 38, no. 12, pp. 3330-3337.
- Harte, P.T., Ayotte, J.D., Hoffman, A., Révész, K.M., Belaval, M., Lamb, S., Bohlke, J.K., 2012, Heterogeneous redox conditions, arsenic mobility, and groundwater flow in a fractured-rock aquifer near a waste repository site in New Hampshire, USA: *Hydrogeology Journal* 20 (6), 1189-1201
- Homestake Mining Co., 2015, Summary and Discussion of Groundwater Background Concentrations and Groundwater Flow for Aquifers at Homestake Mining Company's Grants Reclamation Project, Grants New Mexico, July 2015; Homestake Mining Co. of California.
- Hydro-Engineering, LLC., 2001, Ground-water hydrology for support of background concentration at the Grants Reclamation Site for Homestake Mining Company of California.
- Kaufman, R.F., Eadie, G.G., and Russell, C.R., 1976, Effects of uranium mining and milling on ground water in the Grants Mineral Belt, New Mexico: *Ground Water Journal*, v.14, no. 5, pp. 296-308.
- Langman, J.B., Sprague, J.E., and Durall, R.A., 2012, Geologic framework, regional aquifer properties (1940s–2009), and spring, creek, and seep properties (2009–10) of the upper San Mateo Creek Basin near Mount Taylor, New Mexico: U.S. Geological Survey Scientific Investigations Report 2012–5019, 96 p.
- Meyers, Tom, 2015, Conceptual Flow and Transport Model Uranium Plume near the Homestake Millsite, Milan, NM, March 16, 2015
- Newsome, Laura, Morris, Katherine, Lloyd, J.R., 2014, The biogeochemistry and bioremediation of uranium and other priority radionuclides: *Chemical Geology*, v. 363, pp. 164-184.
- Vroblesky D. (USGS), Scheible W. and Teall G (Columbia Analytical Services (CAS)), 2003. Laboratory Equilibration Study of Nylon-Screen Passive Diffusion Samplers for VOCs, and Select Inorganics. Presented at ITRC Spring Meeting, March 2003, Annapolis MD.

Vroblesky, D.A., Petkewich, M., and Campbell, T., 2002. *Field Tests of diffusion Samplers for Inorganic Constituents in Wells and at a Ground Water Discharge Zone*. USGS Water Resources Investigations Report 02-0431.

Vroblesky, D. A., J. Manish, J. Morrell, and J. E. Peterson, 2003, Evaluation of passive diffusion bag samplers, dialysis samplers, and nylon-screen samplers in selected wells at Andersen Air Force Base, Guam, March-April 2002: U.S. Geological Survey Water-Resources Investigations Report 03-4157, 36 p.

Wu, W.M., Carley, J., Green, S.J., Luo, J., Kelly, S.D., Van Nostrand, J., Lowe, K., Mehlhorn, T., Carroll, S., Boonchayanant, B., Lofler, F.E., Watson, D., Kemner, K.M., Zhou, J.Z., Kitanidis, P.K., Kostka, J.E., Jardine, P.M., Criddle, C.S., 2010. Effects of nitrate on the stability of uranium in a bio-reduced region of the subsurface. *Environ. Sci. Technol.* v.44, pp. 5104–5111.

Yabusaki, S.B., Fang, Y., Long, P.E., Resch, C.T., Peacock, A.D., Komlos, J., Jaffe, P.R., Morrison, S.J., Dayvault, R.D., White, D.C., Anderson, R.T., 2007. Uranium removal from groundwater via in situ biostimulation: field-scale modeling of transport and biological processes: *J. Contam. Hydrol.* v.93, pp. 216–235.

Zielinski, R.A., Chafin, D. T., Banta, E. R., Szabo, B. J., 1997, Use of ²³⁴U and ²³⁸U isotopes to evaluate contamination of near-surface groundwater with uranium-mill effluent: a case study in south-central Colorado, U.S.A.: *Environ. Geology*, v.32, issue 2, pp. 124-136

TABLE 2. ANALYTICAL AND WELL SELECTION LIST

NAME	AQUIFER	Field values	Dissolved ferrous iron	Dissolved oxygen	Alkalinity	Total organic carbon	Major anions	Major cations	Trace elements	Nitrogen	Gross alpha/beta	Radium isotopes
MO	A	X	X	X	X	X	x	x	x	x	x	x
T11	A	X	X	X	X	X	X	X	X	X	X	X
ST	A	X	X	X	X	X	X	X	X	X	X	X
MV	A	X	X	X	X	X	x	x	x	x	x	x
DD	A	X	X	X	X	X	x	x	x	x	x	x
DD2	A	X	X	X	X	X	x	x	x	x	x	x
ND	A	X	X	X	X	X	x	x	x	x	x	x
P3	A	X	X	X	X	X	x	x	x	x	x	x
916	A	X	X	X	X	X	x	x	x	x	x	x
920	A	X	X	X	X	X	x	x	x	x	x	x
n-17	A	X	X	X	X	X	x	x	x	x	x	x
Q	A	X	X	X	X	X	x	x	x	x	x	x
CW50	UC	X	X	X	X	X	x	x	x	x	x	x
CW18	UC	X	X	X	X	X	x	x	x	x	x	x
CE7	UC	X	X	X	X	X	x	x	x	x	x	x
CW2	MC	X	X	X	X	X	x	x	x	x	x	x
CW15	MC	X	X	X	X	X	x	x	x	x	x	x
820	MC	X	X	X	X	X	x	x	x	x	x	x
CW28	MC	X	X	X	X	X	x	x	x	x	x	x
CW1	MC	X	X	X	X	X	x	x	x	x	x	x
484	MC	X	X	X	X	X	x	x	x	x	x	x
ACW	MC	X	X	X	X	X	x	x	x	x	x	x
CW45	MC	X	X	X	X	X	x	x	x	x	x	x
CW26	LC	X	X	X	X	X	x	x	x	x	x	x
CW37	LC	X	X	X	X	X	x	x	x	x	x	x
INJECTATE		X	X	X	X	X	x	x	x	x	x	x

x sample H SAMPLE BUT HOLD

TABLE 2. ANALYTICAL AND WELL SELECTION LIST

NAME	Radon-222	Uranium isotopes	Stable isotopes of water	Sulfur isotopes of sulfate	Nitrogen isotopes	Carbon 13	Carbon-14	Dissolved gases	Tritium/Helium-3	CFCs	Helium-4
MO	x	x	x	X		x		x	H		
T11	X	X	X	X	X	X	X	X	H		
ST	X	X	X	X				X	H		
MV	x	x	x	X		x		x	H		
DD	x	x	x	x	x	x	X	x	H		
DD2	x	x	x	x	x	x	X	x	x	x	X
ND	x	x	x	X	X	x		x	H		X
P3	x	x	x	X				x	H		
916	x	x	X				X	X	H		
920	x	x	X				X	X	H		
n-17	x	x	x	x	x	x	X	x	H		
Q	x	x	x	x	x	x	X	x	x	x	
CW50	x	x	x	X	NO, LOW N	x	x	x	x	x	x
CW18	x	x	x	X		x	x	x	x	x	x
CE7	x	x	x	x	x	x	x	x	H		
CW2	x	x	x	X	X	x	x	x	H	SELECT 3	x
CW15	x	x	x	X	NO, LOW N	x	x	x	H		x
820	x	x	x	X		x	x	x	H		x
CW28	x	x	x	X		x	x	x	H		x
CW1	x	x	x	X	X	x	x	x	H		x
484	x	x	x	X		x	x	x	H		x
ACW	x	x	x	X		x	x	x	H		x
CW45	x	x	x	X		x	x	x	H		x
CW26	x	x	x	none		x	x	x	H	one of ths gr	x
CW37	x	x	x	X	X	x	x	x	H	?	x
INJECTAT	x	x	x	x	x	x	x	x	H		

x